PERFLUOROPOLYETHER PRIMARY BROMIDES AND IODIDES

FIELD OF THE INVENTION

The invention replaces to a perfluoropolyether primary bromide or iodide and to a process therefor.

BACKGROUND OF THE INVENTION

The trademarks and trade names used herein are shown in upper cases.

Perfluoropolyether primary bromides and iodides are a family of highly useful and reactive chemicals that can be used, for example, as lubricants, surfactants, and additives for lubricants and surfactants. *See, e.g.*, Journal of Fluorine Chemistry 1999, 93, 1 and 2001, 108, 147 (hereinafter "Brace"). Brace discloses addition of iodides to alkenes, alkynes, allyls, etc to produce secondary iodides that have limited uses. Brace does not disclose the synthesis of valuable primary perfluoropolyether iodides.

The Hundsdiecker reaction (Journal of Organic Chemistry 1967, 32, 833) deals with reacting silver salts of the perfluoroalkyl carboxylic acid with free iodine. Such a reaction involves expensive reagents and is of limited commercial utility. Journal of Fluorine Chemistry 1993, 65, 59 (hereinafter "Eapen") discloses converting a hexafluoropropylene oxide (HFPO) tetramer acid fluoride to a secondary iodide. See also, US Patents 5,278,340 and 5,288,376 (halogen exchange of the fluorine in the acid fluoride with iodine using metal iodides and aprotic/polar solvent and exposing the acid iodide to ultraviolet irradiation, forming only the secondary iodide).

Journal of Fluorine Chemistry 1997, 83, 117 discloses exposing a molar excess of lithium iodide to low molecular weight perfluoroether acid fluorides at 180 °C for at least 6.5 hours to produce two low molecular weight perfluoropolyether iodides, one primary and one secondary.

US Patent 5,453,549 discloses a low molecular weight ethylene derivative of a primary iodide. It does not disclose the value of higher

molecular weight products. Nor does it disclose the method of synthesis of the starting materials.

Journal of Fluorine Chemistry, 1990, 47, 163 discloses the feasibility of the formation of a primary iodide, in the gas phase, from dimer and trimer of hexafluoropropylene oxide.

While a polyfluorocarbon acid halide can likewise be converted to an iodide in a perhalogened solvent using iodine and a metal carbonate, US Patent 4,973,762, subsequent removal of the solvent can be expensive and undesired traces can be left behind.

Mono-functional (Φ-$CF(CF_3)CF_2OCF(CF_3)C(O)$-F; Formula I) and di-functional ($FC(O)CF(CF_3)OCF_2CF(CF_3)$-$\Phi'$-$CF(CF_3)CF_2OCF(CF_3)C(O)F$; Formula II) acid fluorides, which can be used in the present invention can be prepared according to Moore, US Patent 3,332,826 and Koike et al., US Patent 5,278,340 where Φ and Φ' are respectively monovalent and divalent perfluoropolyether moieties. Additionally, other acid fluorides of Formulae I and II are the reaction products formed from the polymerization of hexafluoropropylene oxide alone or with suitable starting materials, 2,2,3,3-tetrafluorooxetane, or the photooxidation of hexafluoropropylene or tetrafluoroethylene.

Secondary iodides from said acid fluorides can be prepared, for example at 0 - 60 °C using radiation from a photochemical lamp (for instance a lamp with an ultra-violet light output in the wavelength range of 220 - 280 nm (US Patent 5,288,376)).

The usefulness of this invention is demonstrated, for example, by the reactions of primary perfluoropolyether iodides with bromobenzene which could lead directly to perfluoropolyether substituted bromobenzene without the use of toxic or pyrophoric chemicals such as sulfur tetrafluoride or butyl lithium. These functionalized perfluoropolyether (PFPE) intermediates are used to form readily soluble, high temperature additives for fluorinated oils in boundary lubrication, as disclosed in Eapen and US Patent 5,550,277. These primary bromides or iodides described herein

can also be used as intermediates in the production of fluorous phase media for applications such as catalysis (Horváth, I., Acc. Chem. Res. 1998, 31, 641) or separations (Curran, D. P. Angew. Chem., Int. Ed. Engl. 1998, 37, 1174), fluorosurfactants, and mold release agents.

Because there are few useful perfluoropolyether primary bromides or iodides and processes for producing them are not readily available to one skilled in the art, there is an ever increasing need to develop such products and processes.

SUMMARY OF THE INVENTION

A perfluoropolyether and a composition comprising the perfluoropolyether are provided in which the perfluoropolyether comprises at least one halogen atom at the primary position of one or more end groups of the perfluoropolyether and the halogen atom is bromine or iodine.

Also provided is a process for producing the composition in which the process comprises contacting either (1) a perfluoropolyether acid fluoride with a metal bromide or metal iodide or (2) heating a perfluoropolyether secondary halide under a condition sufficient to effect the production of a perfluoropolyether comprising at least one bromine or iodine at the primary position of one or more end groups of the perfluoropolyether.

DETAILED DESCRIPTION OF THE INVENTION

A common characteristic of perfluoropolyethers is the presence of perfluoroalkyl ether moieties. Perfluoropolyether is synonymous to perfluoropolyalkylether. Other synonymous terms frequently used include "PFPE", "PFPE oil", "PFPE fluid", and "PFPAE".

Examples of the inventive perfluoropolyether primary bromide or iodide include, but are not limited to, those having the formulae of $F(C_3F_6O)_zCF(CF_3)CF_2X$, $X(CF_2)_a(CF_2O)_m(CF_2CF_2O)_n(CF_2)_aX$, $F(C_3F_6O)_x(CF_2O)_mCF_2X$, $F(C_3F_6O)_x(C_2F_4O)_n(CF_2O)_mCF_2X$,

$XCF_2CF(CF_3)O(C_3F_6O)_pR_f^2O(C_3F_6O)_nCF(CF_3)CF_2X$, $XCF_2CF_2O(C_3F_6O)_xCF(CF_3)CF_2X$, $(R_f^1)(R_f^1)CFO(C_3F_6O)_xCF(CF_3)CF_2X$, and combinations of two or more thereof where X is I or Br; x is a number from 2 to about 100; z is a number of about 5 to about 100, preferably 5 to about 100, more preferably at least about 6, and even more preferably 6 to 90, or 8 to 90 such as, for example, about 6, about 7, about 8, or about 52; p is a number from 2 to about 50, n is a number from 2 to about 50, m is a number from 2 to about 50, a is 1 or 2, each R_f^1 can be the same or different and is independently a monovalent C_1 to C_{20} branched or linear fluoroalkanes, R_f^2 is a divalent C_1 to C_{20} branched or linear fluoroalkanes, and C_3F_6O is linear or branched.

The composition of the invention can be produced by any means known to one skilled in the art. It is preferred that it be produced by the process disclosed herein.

According to the invention, a process for producing the composition disclosed above can comprise, consist essentially of, or consist of contacting either (1) a perfluoropolyether acid fluoride or diacid fluoride containing a COF moiety with a metal bromide or metal iodide or (2) heating a perfluoropolyether secondary halide under a condition sufficient to effect the production of a perfluoropolyether comprising at least one bromine or iodine at the primary position of one or more end groups of the perfluoropolyether. The process generally involves a β-scission reaction. The process is preferably carried out under a condition or in a medium that is substantially free of a solvent or iodine or both. The process can also be carried out substantially free of a metal salt that is not a metal halide.

The acid fluoride including monoacid fluoride and diacid fluoride of Formula I and II, respectively, can be contacted with a metal iodide such as lithium iodide, calcium iodide, or barium iodide to make either a secondary or primary perfluoropolyalkylether iodide with the evolution of carbon monoxide and formation of the metal fluoride according to Reaction 1 for the monofunctional acid fluoride and Reaction 2 for the

difunctional acid fluoride. These reactions can be carried out at or above about 180 °C, preferably at or above about 220 °C.

Reaction 1: $\Phi\text{-}CF(CF_3)CF_2OCF(CF_3)C(O)\text{-}F + M_{(1/v)}I \rightarrow$
$\Phi\text{-}CF(CF_3)CF_2\text{-}I + M_{(1/v)}F + CO + CF_3C(O)F$

Reaction 2: $FC(O)CF(CF_3)OCF_2CF(CF_3)\text{-}\Phi'\text{-}CF(CF_3)CF_2OCF(CF_3)C(O)F + 2M_{(1/v)}I \rightarrow ICF_2CF(CF_3)\text{-}\Phi'\text{-}CF(CF_3)CF_2I + 2M_{(1/v)}F + 2CO + 2CF_3C(O)F$
where Φ, Φ' are as previously described, M is a metal selected from Li, Ca, or Ba, and v is the valency of the metal M.

A perfluoropolyether acid fluoride containing a $-CF_2OCF(CF_3)COF$ moiety can be combined with a metal bromide or metal iodide under a condition sufficient to effect the production of a perfluoropolyether primary bromide or iodide. The metal moiety can be an alkali metal, an alkaline earth metal, or combinations of two or more thereof. Examples of suitable metal bromide and metal iodide include but are not limited to, lithium iodide, calcium iodide, barium iodide, aluminum iodide, boron iodide, aluminum bromide, boron bromide, and combinations of two or more thereof. The conditions can include an elevated temperature such as, for example, at or above about 180 °C, preferably at or above about 220 °C, under a pressure that can accommodate the temperature for a sufficient time period such as, for example, about 1 hour to about 30 hours.

The process can also comprise contacting a perfluoropolyether acid fluoride containing a COF moiety in the secondary position such as, for example, $CF(CF_3)CF_2OCF(CF_3)COF$, with a bromide or iodide MX under the conditions disclosed above.

According to the invention, the perfluoropolyether that can be used in the process of the invention can also comprise repeat units derived from the group consisting of $-CF_2O-$, $-CF_2CF_2O-$, $-CF_2CF(CF_3)O-$, $-CF(CF_3)O-$, $-CF(CF_3)CF_2O-$, $-CF_2CF_2CF_2O-$, $-CF(CF_s)O-$, $-CF_2CF(CF_s)O-$, $-CF_2CF(CF_2CF_3)O-$, $-CF_2CF(CF_2CF_2CF_3)O-$, $-CF(CF_2CF_3)O-$,

-CF(CF$_2$CF$_2$CF$_3$)O-, -CH$_2$CF$_2$CF$_2$O-, -CF(Cl)CF$_2$CF$_2$O-, -CF(H)CF$_2$CF$_2$O-, CCl$_2$CF$_2$CF$_2$O-, -CH(Cl)CF$_2$CF$_2$O-, and combinations of two or more thereof.

Perfluoropolyether containing these repeat units are well known to one skilled in the art. For example, KRYTOX available from E. I. du Pont de Nemours and Company comprises the repeat units of -CF(CF$_3$)CF$_2$O-.

The following examples illustrate the invention process.

$F(C_3F_6O)_zCF(CF_3)CF_2OCF(CF_3)I \rightarrow F(C_3F_6O)_zCF(CF_3)CF_2I$ (monofunctional), or

$ICF(CF_3)OCF_2CF(CF_3)O(C_3F_6O)_pR_f^2O(C_3F_6O)_nCF(CF_3)CF_2OCF(CF_3)I \rightarrow ICF_2CF(CF_3)O(C_3F_6O)_pR_f^2O(C_3F_6O)_nCF(CF_3)CF_2I$ (difunctional).

PFPE primary iodides can also be converted to their respective PFPE primary bromides by contacting them with carbon tetrabromide, for example, at 180 °C according to $F(C_3F_6O)_zCF(CF_3)CF_2I + CBr_4 \rightarrow F(C_3F_6O)_zCF(CF_3)CF_2Br + ½ I_2 + ½ C_2Br_6$.

PFPE acid fluorides can also be converted to their respective acid bromides by contacting them with mixed metal bromides such as, for example, aluminum bromide mixed with boron bromide. The acid bromide can be isolated. The isolated acid bromide can be heated at elevated temperature such as, for example, about 340 °C.

The following examples illustrate this invention.

EXAMPLES

Example 1.

Preparation of $CF_3(CF_2)_2(OCF(CF_3)CF_2)_{(n-1)}OCF(CF_3)CF_2I$ from the corresponding secondary iodide $CF_3(CF_2)_2(OCF(CF_3)CF_2)_nOCF(CF_3)I$ having n~8.

The polyhexafluoropropylene oxide homopolymer (HFPO) secondary iodide, $CF_3(CF_2)_2(OCF(CF_3)CF_2)_nOCF(CF_3)I$ having n~8, used as the starting material in this example, was made by first adding lithium iodide (Aldrich Chemical, Milwaukee, WI) (117.78 g) to a nitrogen-purged 2-L PYREX round-bottomed flask. KRYTOX Acid Fluoride (907.18 g)

(available from E. I. du Pont de Nemours and Company, Wilmington, DE) was then added to the flask, and the mixture was heated at 180 °C for 15 hours with stirring. The oil was filtered through a CELITE bed and analyzed by mass spectrometry and ^{13}C NMR spectroscopy. From the mass spectrum, fragments at 227 m/z ($-CFICF_3$) and 393 m/z ($-CF(CF_3)CF_2OCFICF_3$) are indicative of the secondary iodide. Nuclear magnetic resonance (NMR) analysis showed the carbon bonded to iodine at 78.1 ppm d,q; $-CFICF_3$; $^1J_{CFI}$ = 314.8 Hz, $^2J_{CF3}$ = 43.3Hz (^{13}C NMR: 75.5 MHz, D_2O/TMS).

Polyhexafluoropropylene oxide homopolymer (HFPO) secondary iodide (200.0 g, prepared as above) was added to a 500-mL PYREX round-bottomed flask and heated to 220 °C for 4 hours with stirring. The oil was filtered through CELITE (a SiO_2 filter aid), and analyzed by mass spectrometry and ^{13}C NMR spectroscopy. The HFPO primary iodide was identified by mass spectrometry analysis, mass fragments of m/z = 277 ($-CF(CF_3)CF_2I$) and m/z = 177 ($-CF_2I$) prove the structure of the desired product. By ^{13}C NMR spectroscopy, peaks specific to the desired product were detected at 93.8 ppm (t,d, $-CF(CF_3)CF_2I$, $^1J_{CF}$ = 332.94 Hz, $^2J_{CF}$ = 33.19 Hz) and at 93.9 ppm (t,d, $-CF(CF_3)CF_2I$, $^1J_{CF}$ = 332.94 Hz, $^2J_{CF}$ = 33.19 Hz). Yield: 187.0 g.

Example 2.

Preparation of $CF_3(CF_2)_2(OCF(CF_3)CF_2)_{(n-1)}OCF(CF_3)CF_2I$ from KRYTOX Acid Fluoride having n~8.

Lithium iodide (187.71 g) was added to a nitrogen purged 2-L PYREX round-bottomed flask. Upon addition of KRYTOX Acid Fluoride (1,651.3 g), the flask was heated at 220 °C for 15 hours with stirring. The oil was filtered through CELITE and determined to be identical to the above product. Yield 1447.6 g.

Example 3.

Preparation of $CF_3(CF_2)_2(OCF(CF_3)CF_2)_{(n-1)}OCF(CF_3)CF_2I$ from KRYTOX Acid Fluoride having n~8.

Calcium iodide (Aldrich Chemical, Milwaukee, WI) (20.72 g) was added to a nitrogen purged 500-mL round-bottomed flask in a dry box. Next, KRYTOX Acid Fluoride (100.00 g) was added, and the mixture was heated at 220 °C for 12 hours with stirring. The product was allowed to cool to room temperature and was filtered through CELITE. The product was consistent with earlier results. Yield 60.62 g.

Example 4.

Preparation of $CF_3(CF_2)_2(OCF(CF_3)CF_2)_{(n-1)}OCF(CF_3)CF_2I$ from KRYTOX Acid Fluoride having n~6.

Barium iodide (Aldrich Chemical, Milwaukee, WI) (5.00 g) was added to a nitrogen purged 50-mL round-bottomed flask. Next, KRYTOX Acid Fluoride (13.1 g) was added to the flask. The reaction mixture was heated at 220°C for 12 hours while stirring. The primary iodide was identified by GC/MS and was consistent with earlier results. Yield: 5.1 g.

Example 5.

Preparation of $CF_3(CF_2)_2(OCF(CF_3)CF_2)_{(n-1)}OCF(CF_3)CF_2I$ from KRYTOX Acid Fluoride having n~52.

Lithium iodide (52.0 g) was added to a nitrogen purged 5-L PYREX round-bottomed flask. Upon addition of KRYTOX Acid Fluoride (2720 g), the mixture was heated at 220 °C for 20 hours with stirring. The oil was filtered through CELITE and determined to be the desired products. Yield 2231.76 g.

Example 6.

Preparation of $CF_3(CF_2)_2(OCF(CF_3)CF_2)_{(n-1)}OCF(CF_3)CF_2Br$ from the corresponding acid fluoride.

Step 1. 5.57 g $F(CF(CF_3)CF_2O)_5CF(CF_3)COF$, 0.53 g $AlBr_3$ (Aldrich Chemical, Milwaukee, WI), and 2.65 g BBr_3 (Aldrich Chemical, Milwaukee, WI) were loaded into a 75-ml stainless steel cylinder in a glove box. The cylinder was closed with a valve and kept at ambient temperature for 24 h with occasional shaking. After that, the liquid content

was removed with a pipette and filtered. The subsequent ^{13}C NMR spectroscopy shows quantitative conversion of the Acid Fluoride to the acid bromide.

Step 2. Conversion of the acid bromide to the HFPO primary bromide. 3.82 g of product from above was loaded into a 75-ml stainless steel cylinder within a glove box, closed with a valve, evacuated, weighed, and heated to 250 °C for 16 h. Additional heating to 340 °C overnight produced 0.08 g CO and other volatiles. Investigation of the liquid residue by ^{13}C NMR spectroscopy showed total disappearance of the acid bromide and new signals for the primary bromide. Along with the other signals expected, the chemical shift for the $-CF_2Br$ carbon is found at $\delta = 115.6$ ppm; t, d; $^1J_{CF2} = 313.8$ Hz, $^2J_{CF} = 32.5$ Hz thus establishing the identity of the desired product.

Example 7.

Preparation of $CF_3(CF_2)_2(OCF(CF_3)CF_2)_nOCF(CF_3)CF_2Br$ from the corresponding Iodide.

Poly(hexafluoropropylene oxide) primary iodide (469.3 g) prepared, as in Example 3, was added to a nitrogen purged 500-ml round-bottomed flask. With stirring, carbon tetrabromide (Aldrich Chemical, Milwaukee, WI) (115.9 g) was charged to the flask and heated slowly to 175-185 °C and held at that temperature for 3 days. The primary bromide was identified by mass spectrometry, with mass fragments of m/z = 229 and m/z = 231 ($-CF(CF_3)CF_2Br$) and m/z = 129 and m/z = 131 ($-CF_2Br$) being indicative of the HFPO primary bromide. Yield: 299 g.

Comparative Example A

(Method A) A thermal reaction was attempted between KRYTOX Acid Fluoride and sodium iodide (Aldrich Chemical, Milwaukee, WI) at a temperature of 220 °C. Sodium iodide (27.11 g) and KRYTOX Acid Fluoride (186.34 g) were added to a nitrogen purged 500-ml round-bottomed flask equipped a thermocouple and reflux condenser. The

reactants were heated at 220°C for 12 hours while stirring. The product was filtered through CELITE and analyzed with mass spectrometry. No reaction was observed.

(Method B) A reaction was attempted between KRYTOX Acid Fluoride, sodium iodide, and acetonitrile at 50 °C to reproduce prior art as reported in US Patent 5,278,340. Sodium iodide (42.85 g) and KRYTOX Acid Fluoride (160.00 g) were added to a nitrogen purged 250-ml round-bottomed flask equipped with a thermocouple and reflux condenser. Next, acetonitrile (7.00 g) was added. The reactants were stirred while heating at 50 °C for 12 hours. The product was filtered through CELITE and analyzed by mass spectrometry. No reaction was observed.

Comparative Example A demonstrates that sodium iodide alone or sodium iodide dissolved in acetonitrile does not form a poly(hexafluoropropylene oxide) iodide.

Comparative Example B

Potassium iodide (Aldrich Chemical, Milwaukee, WI) (36.52 g) was added to a nitrogen purged 500-ml round-bottomed flask and heated at 110 °C for 30 min to dry the salt. Next, KRYTOX Acid Fluoride (226.79 g) was added to the flask and the contents of the flask were heated at 180°C for 12 hours. After the reaction, the product was filtered through CELITE and analyzed by mass spectrometry. No reaction was observed.

Comparative Example B demonstrates that potassium iodide cannot be used to form a poly(hexafluoropropylene oxide) iodide.

Comparative Example C

Lithium bromide (Aldrich Chemical, Milwaukee, WI) (25.0 g) was added to a nitrogen purged 50-ml round-bottomed flask. Next, KRYTOX Acid Fluoride (149.0 g) was added to the reaction flask. The reaction mixture was heated at 220°C for 12 hours with stirring. The product was washed with methanol, then water, and analyzed by mass spectrometry. No reaction was observed.

Comparative Example C demonstrates that lithium bromide cannot be used to form a poly(hexafluoropropylene oxide) bromide.